Vol. 12, 2023, 51-62

sciendo

DOI: 10.17512/bozpe.2023.12.06

Construction of optimized energy potential
Budownictwo o zoptymalizowanym potencjale energetycznym

ISSN 2299-8535 e-ISSN 2544-963X

# A thermo-circulating heating structure utilizing air circulation to heat architectural objects

**Bogusław Szuba**[1] (*orcid id: 0000-0001-8732-7345*)
[1] University of Applied Sciences in Nysa, Poland

Abstract: The article focuses on a method of heating buildings by utilizing warm air circulation in closed channels located within external walls, referred to as "collector walls" by the author. These channels are also present in the roof and floors, creating a closed-loop system of interconnected air spaces that form a thermo-circulating heating structure. When the collector walls receive favourable solar exposure from the south, east, or west, the air circulating within the thermo-circulating heating structure is naturally heated through solar radiation, resulting in passive heating. However, in cases where solar radiation is insufficient, an external heat source is re-quired. Heating elements can be directly incorporated into the convection, such as in the lower part of the collector wall.

Keywords: passive heating, collector walls, warm accumulation, hypocaustum



**Please, quote this article as follows:**

Szuba B., A thermo-circulating heating structure utilizing air circulation to heat architectural objects, Construction of Optimized Energy Potential (CoOEP), Vol. 12, 2023, 51-62, DOI: 10.17512/bozpe.2023.12.06

## Introduction

The article explores heating solutions used in thermal baths and private houses, specifically focusing on the implementation of the Hypocaustum system, which originated in ancient Greece and Rome. The Hypocaustum system consists of the following components:

- raised floor on pillars called *pilae*, on which the ceilings were laid and lined with a layer of tiles submerged in a layer of concrete, then covered with ceramic tiles;
- ducts built into the walls lined with ceramic tiles to remove warm air and smoke from the furnace above the roof;
- a furnace placed under the floor in the immediate vicinity of the heated room. This furnace functions as a heat source that distributes heat through combustion.

* Corresponding author: boguslaw.szuba@pans.nysa.pl

The rooms requiring the greatest heat were located closest to the furnace and the heat adjusted by increasing the amount of fuel. The construction of a *hypocaustum* was a labour-intensive process that required constant supervision. As the system was expensive to build and operate, it was primarily used in private villas and public baths.

The inventor of the device was credited to be the Roman engineer Sergius Orata in the early 1st century BCE, although he probably only improved upon an earlier known Greek invention. Orata is mentioned by Waleriusz Maximus in "*The Natural History of Pliny*" as the first individual to use the *hypocaustum* to heat a pool intended for fish and oyster farming.

The hypocaust was modified over time. In the medieval period, it differed from the ancient version mainly by adding a heat accumulator in the form of stones. The system was used in monasteries (Bojęś-Białasik, 2019), as well as castles like the Teutonic castle in Malbork (Nawrot, 2018; Pospieszna, 2010) (Figs. 1-3) and even in tenement houses, as seen in Toruń (Skonieczny, 2008).

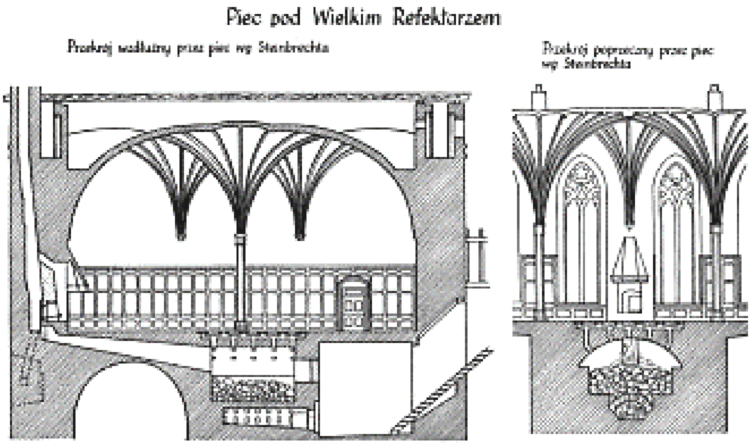


**Fig. 1.** The furnace under the great refectory (Nawrot, 2018)

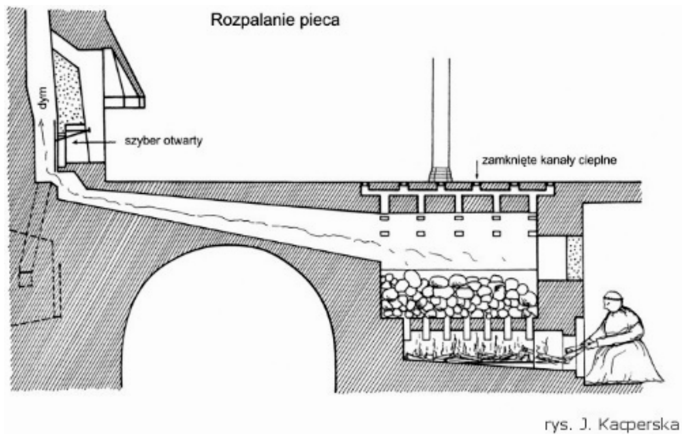


**Fig. 2.** Firing up the furnace (Pospieszna, 2010)

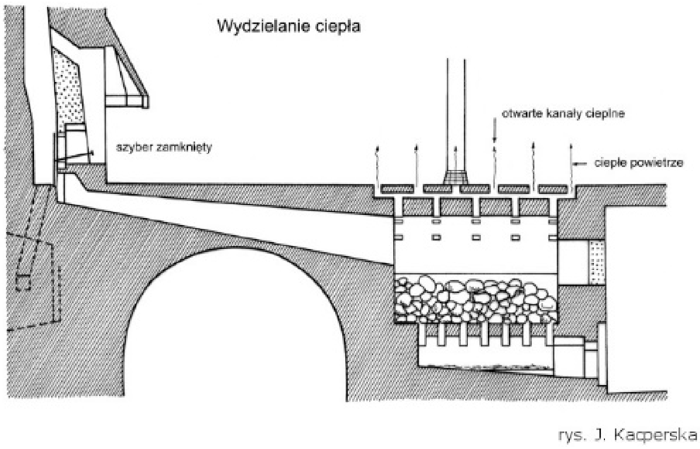


**Fig. 3.** Heat release (Pospieszna, 2010)

Examples of solutions using hypocaust pipe heating systems can be found in many scientific sources, for example: Lauriacum, a former Roman military camp (Lorch), and in a bishop's residence in Geneva (Bingenheimer, 1998).

In Poland, the *hypocaustum* was used from the thirteenth to the sixteenth century. It was brought by Germanic settlers and Cistercians and used for instance in the Cisterian monasteries in Sulejów (Augustyniak, 1990; Augustyniak, Grzybkowski & Kunkel, 1992), Lubiąż (Buśko, 1995; Łużyniecka, 1987; Łużyniecka, 1988), and Wąchock (Baliliunaité & Žalnierius,1996). Another example dated to the 13th century can be found on Ostrów Tumski in Wrocław (Buśko, 1995; Małachowicz, 1994).

Research into the hypocaustum system was conducted by C. Buśko, K. Dymek, J. Piekarski (Buśko, Dymek & Piekarski, 1991; Buśko, 1997; Buśko & Dymek, 1995; Buśko & Dymek, 1999).

Around the fourteenth century, this system began to be replaced by tiled stoves, which were cheaper to build and operate.

Similar to the Roman *hypocaustum* is the traditional *ondol* underfloor heating system used in Korea (Gook-Sup Song, 2005) (Fig. 4). The main components are: a fireplace or stove (also used for cooking) located under the floor, stone pillars forming a system of heat channels heating the floor, and a vertical chimney.

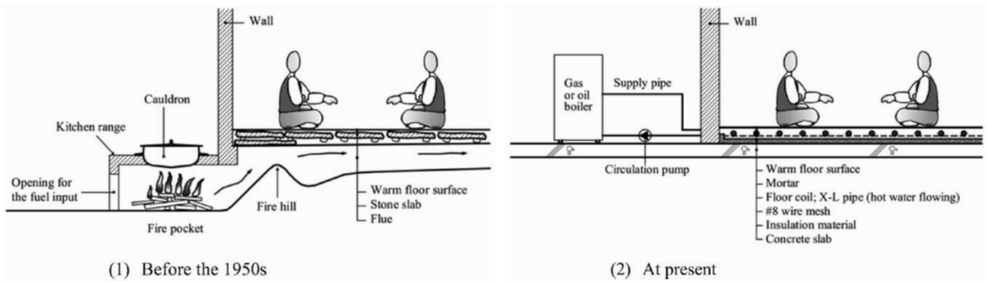


**Fig. 1.** Ondol underfloor heating system used in Korea (Gook-Sup Song, 2005)

The pillars consist of stone slabs, a layer of clay and an impermeable layer, such as oil-soaked paper. The ondol was used in Buddhist monasteries, in resting places, and where people sat. Warmer places were reserved for guests of honor.

Nowadays, there are buildings projects equipped with DSF (Double Skin Façade) systems. Typically, it is constructed from two transparent glass curtains, separated from each other by an air void, creating a ventilated channel (Fig. 5).

The way the air stream flows through the façade is one of the main criteria for the DSF classification. Classification is based on the source and intended purpose of the air transported through the gap space. The figure below provides schematic illustrations of the following distinguished solutions:

a) air buffer – no air exchange. Both glass coatings that form the façade are made in a tight manner, without openings;
b) internal air curtain – there is internal air circulation between the room and the façade, often supported mechanically; the flowing air creates a curtain surrounding the inner part of the façade;
c) air inlet – in this case, fresh air is taken from the outside through a ventilation gap and introduced into temperature-controlled rooms;
d) external air curtain - air flowing in the façade is taken and then thrown outside the façade, where it forms a curtain;
e) air launcher – used air is extracted from the inside and released through the ventilation duct;
f) a solution characterized by a leaky outer coating that allows adjustment of the degree of leakage.

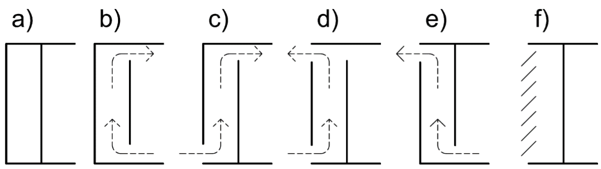


**Fig. 5.** Double Skin Façade (Author's drawing based on Heim, 2013)

Solutions b and c are recommended during the heating period, as they allow direct use of heat gains from solar radiation, while solutions d and e support the cooling system of the rooms.

## 1. Insights

Despite numerous examples of heating rooms in buildings with warm air flowing through gaps in the walls, these solutions are not without disadvantages. Warm air is obtained from artificial heat sources, usually using fossil fuels. Air that passes through the heating channels is released through the holes to the outside, causing significant losses of thermal energy. In other cases, warm air is released directly into the heated room, leading to the need to extinguish the furnace serving as a heat source. This is necessary to prevent harmful exhaust gases and excessive temperature and thus the generated heat energy is not fully utilized. In previous solutions, if materials that could accumulate thermal energy were used (usually stones placed above the hearth), their thermal energy storage properties were limited by their size, which could not be too large due to the space available in the basement.

## 2. Proposal

Heating ducts (**KG**) interconnected in a closed loop create a space that allows the cyclic flow of warm air. Warm air does not enter the heated rooms and is not expelled outside of the facility. This increases the efficiency of the heating system. Heat can be produced from a renewable source such as solar radiation. The heat accumulator (**AC)** is not limited by the size of the basement. It can be located under the building (Fig. 6).

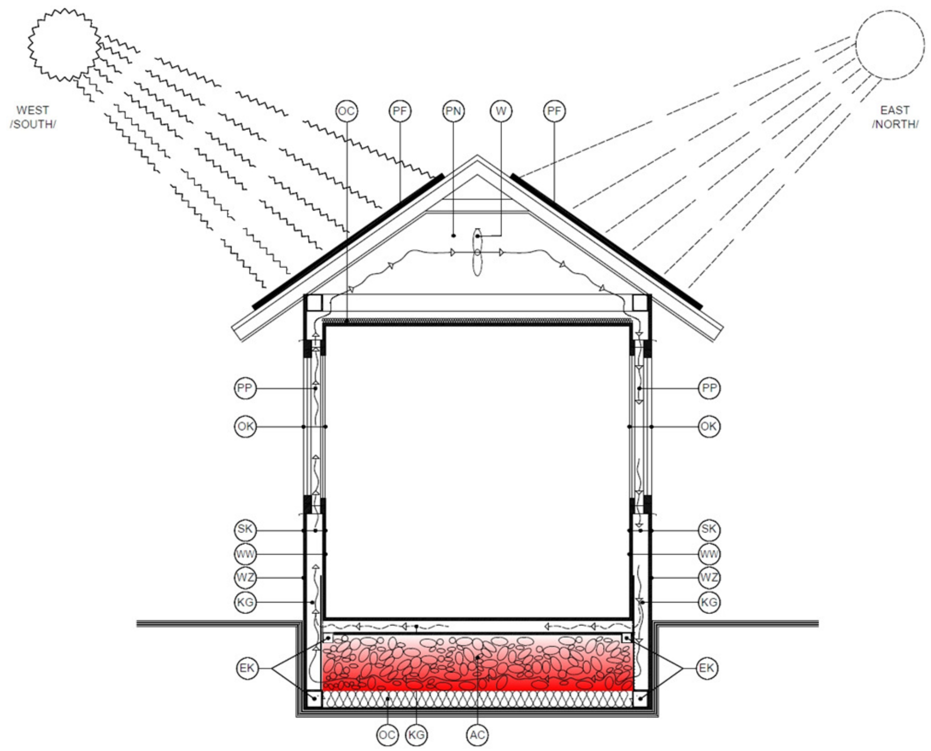


**Fig. 6.** Diagram of the thermocirculation heating structure in the building: roof, high principle of passive heating operation with possible fan suport: SK – wall with the structure of an air solar collector; WW – inner layer painted on both sides with thermoreflective paints; WZ – outer layer absorbing thermal energy; KG – air heating ducts; AC – heat accumulator; EK – building structural elements; OC – isolation; PN – non-usable attic (additional heat collector); W – fan powered by photovoltaic cells; PF – photovoltaic panels; OK – collector window; PP – direction of heated air flow (*own research*)

The *thermocirculating heating structure* of buildings consists of:

- Air heating ducts (**KG)** located in the external partitions of the building:
  - collector walls (**SK**) that collect heat from solar radiation,
  - ceilings (**S**), in multi-storey buildings,
  - flat roof (**SD)**, where applicable,
  - non-usable attic (**PN)**, in buildings with a high roof, these require an additional solar collector.

  These components form the *thermocirculation heating structure* used for distributing, and transferring heat to rooms.
- A heat accumulator (**AC)** located in the airflow to facilitate convection.

**Usable heat sources in cases when the solar heating of the collector walls is insufficient:**

- traditional devices (based on the collection of energy accumulated in fuel), with heating elements located directly in the convection space (in the lower part of the collector wall),
- modern equipment (heat pumps, heat generated from refrigeration units, air conditioners, convectors, etc.).

**Construction of the external collector wall:**

The collector wall consists of two material layers:

- external (**WZ**), e.g. a fiber-cement board of dark color, dark metal panels, etc.,
- internal (e.g. plasterboard painted on the inside and outside with a thermo-reflective coating).

These layers are separated from each other by an air void. Additionally, double windows can serve as elements of the collector wall, functioning as air solar collectors. The thermocirculation heating structure scheme has been implemented in the design of small houses for seniors, as described below.

## 3. The principle of operation of the passive air thermocirculation heating structure

The operation of the structure follows a two-stage process:

a. Charging the heat accumulator (AC) with a flow of warm air through looped channel.

The air flow through the ducts (KG) of the thermocirculation structure is caused by heating the collector wall with solar radiation. Due to the varying intensity of solar radiation on different sides of the building, the opposite collector walls are heated unevenly. This temperature difference creates a phenomenon of air circulation, with warmer air particles rising and cooler air descending. As the warm air passes through the material filling the heat accumulator (such as a stone composition or horizontally arranged unfired clay bricks), the heat accumulator is heated. Air movement occurs during sunny days when there are temperature differences between the opposite collector walls. Therefore, the system operates according to the daily cycle, specifically during the impact of solar radiation. Consequently, the heat accumulator is heated rather than cooled during the night.

b. Heat discharge from the heat accumulator (AC). Heat rises through the floor and heats the room.

Heat release from the battery can be done in two ways:

– radiating heat directly to the floor,
– heating of the air in the duct above the heat accumulator, which is induced to move by convection caused by uneven heating from solar rays in the air ducts located on opposite collector walls.

The warm air circulating in the channels of the thermocirculation heating structure heats the rooms of the building.

The air gap occurring in the thermocirculation heating structure acts as a buffer space that helps reduce the temperature difference between the interior of the room and the air of the external environment. By distributing the temperature difference in steps, the flow of heat from the building is minimized.

The efficiency of the thermocirculation heating structure can be increased by using mechanical air flow support such as a fan. It is best to power the fan from renewable energy sources, such as electricity generated in real-time by photovoltaic panels. During the day, when the sun supplies thermal energy to Earth and photons fall on the panels, they generate an electric current. At night, when the solar radiation stops, no electricity is produced. Therefore, the fan does not work and does not cool the heat accumulator with cold air. Consequently, the operation of the air thermocirculation heating structure is completely dependent on the natural daily cycles of day and night and takes place independently of additional technical devices.

## 4. The benefits of air heating buildings

- For new buildings, the cost of implementing a thermocirculation heating structure is relatively low. This is because the structure of the building and the heating channels between its elements form an integrated system. The hot air is obtained as an added value without the need for external channels outside the building's structural system.
- For existing buildings, including historic ones with unique external facades, the thermocirculation heating structure can be implemented by adding an additional material layer to the internal side of the external partitions. The combination of thermoreflective paints, which preserve the external architectural details, along with the thermocirculation heating structure, allows for achieving contemporary thermal parameters for the building.
- The thermocirculation heating structure does not require additional transmission devices.
- The thermocirculation heating structure can act as a supporting construction of the building.
- The above, specified in points 3 and 4, creates the premises of an extremely economical solution.

- Negligible heat transmission.
  - In the case of using traditional heat sources, structures and the thermal convection, this construction and heating, and at the same time obtains energy from the heat source and gives off heat to the interior of the building.
  - In the case of passive heating of the collector walls by the Sun, the loss of energy flow to the heat accumulator (AC) will / can be minimised by forcing the fan to accelerate the movement of warm air.
- The location of the heat source may involve the use of a non-usable attic or a heat accumulator, which does not involve the need to organize an additional room.
- The very low probability of defects (in particular, the use of RES). The operational foundation of the thermocirculation heating structure is a natural process.
- Low operating costs is also beneficial.

## 5. Application of thermocirculating heating structures

The efficiency of the proposed structure, aimed at minimizing the circulation of hot air, is most effective in small architectural structures, such as:

- Housing, especially small residential houses, multi-family houses, seasonal or year-round recreation facilities.
- Public utility construction: office pavilions, catering facilities, tourist information buildings, cloakroom and sanitary facilities in sports and recreational facilities, commercial and service facilities, cosmetic and hairdressing facilities etc.
- Technical construction: transformer stations, warehouse facilities, cold stores.
- And many others.

When using additional means to support the circulation of heated ventilation, architectural objects heated by this method can be significantly larger. The author participated in an international project aimed at searching for methods of eliminating energy poverty in EU countries. Energy poverty particularly affects older people.

An original program of supporting seniors and supporting the eradication of energy poverty was created:

- A family owning a large apartment that does not have the means to maintain it receives a proposal to replace it with a microhouse (a house consisting of functional modules) offered by a developer, organisation, local government or other entity acting for the benefit of sensitive people.
- The difference in the market price of the apartment and the price of a microhouse (in the most favourable case resulting from non-profit activities) is to be a source of income consumed for the further activity of the unit supporting a group of vulnerable people.
- A significant difference resulting from the cost of maintaining a microhouse in relation to bills paid for a previously used apartment is that in the case of a microhouse, bills are minimal or close to zero.
- An incentive for groups of people who need to convert a dwelling into a microhouse is to be not only a significant reduction in bills, but also an interesting, safe location of the house, close to nature and a garden.

Using the above-described technical solutions, the author designed a complex of small residential houses for seniors in the village of Kamionek in the Opole province, Krapkowice poviat, Gogolin commune (Figs. 7-10).

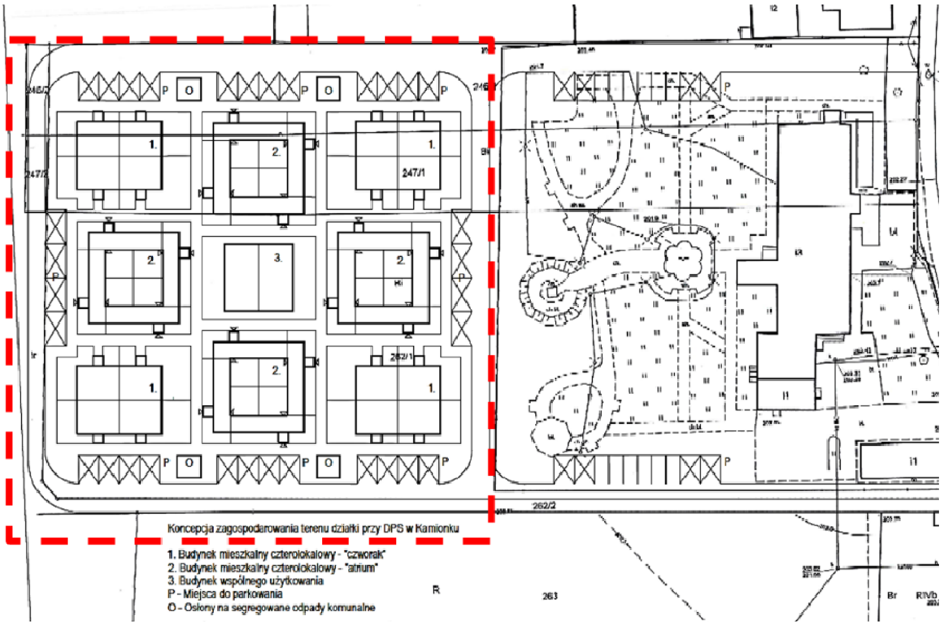


**Fig. 7.** Complex of modular houses – Site plan (*own research*)

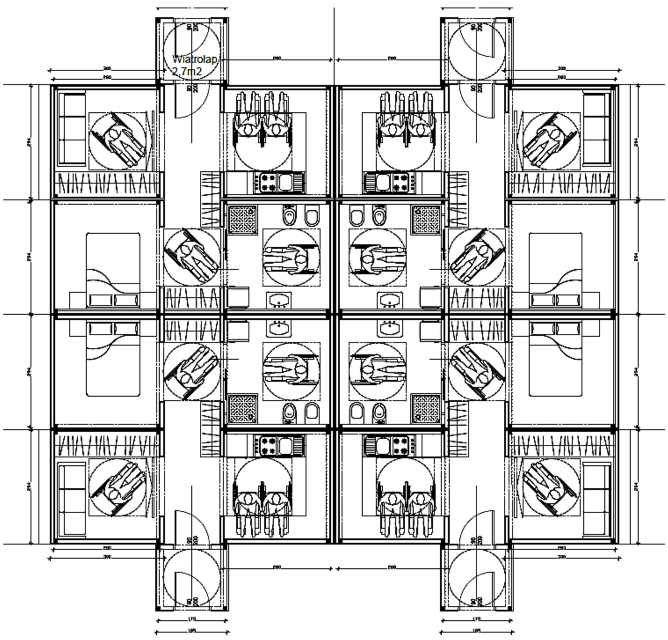


**Fig. 8.** Compact building – 4 residential units fully adapted for people with disabilities "quadruplet", repeatable apartment 41.5 m$^2$ (*own research*)

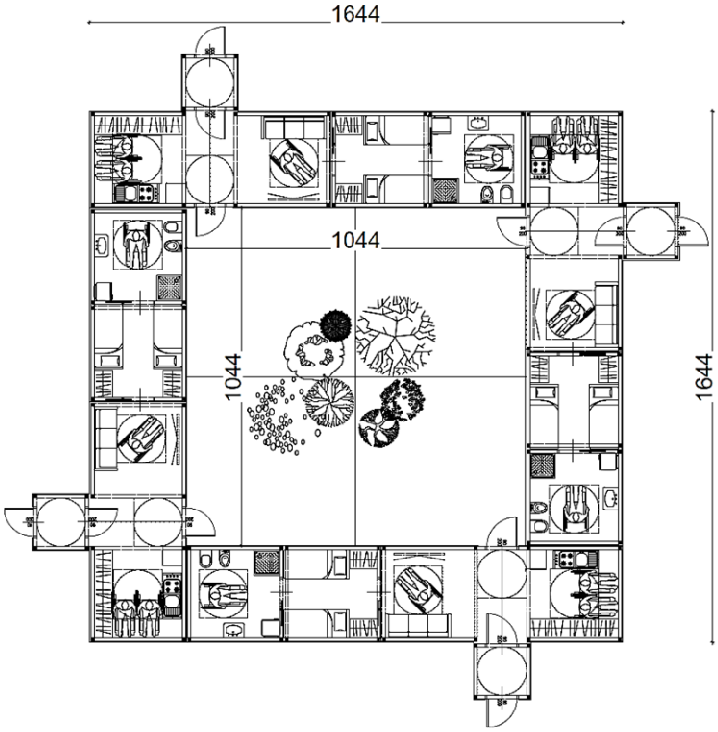


**Fig. 9.** Atrial house – repeatable apartment 37.8 m$^2$ (*own research*)

**Fig. 10.** Visualisation of a complex of modular houses in Kamionek (*own research*)

## Conclusions

The search for energy-saving solutions in construction can involve the development of modernized hypocaust systems. Additionally, the future of energy-efficient architecture is expected to rely heavily on the utilization of heat accumulators. This shift is driven by both economic reasons and the desire to reduce the reliance on technical devices that require electricity.

## Summary

Modern aspirations to implement energy-efficient constructions are largely based on the use of technical devices, such as heat pumps, photovoltaic panels, heat recuperators etc. However, it is important to utilize the possibility of natural phenomena. The improvement of energy parameters of architectural objects can be achieved through simple construction and material methods. The air thermocirculating heating structure described in the article is an example of this type of solution.

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